HUMAN FACTORS FLIGHT TRIAL ANALYSIS FOR 2D SITUATION AWARENESS AND 3D SYNTHETIC VISION DISPLAYS

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Abstract

This article describes the human factor analysis from flight trials performed in Reno, NV. Flight trials were conducted with a Cheyenne 1 from Marinvent. Thirteen pilots flew the Cheyenne in seventy-two approaches to the Reno airfield. All pilots flew completely randomized settings. Three different display configurations:

- Elec. Flight Information System (EFIS),
- EFIS and 2D moving map, and
- 3D SVS Primary Flight Display (PFD) and 2D moving map

were evaluated. They included normal/abnormal procedure evaluation for:

- Steep turns and reversals,
- Unusual attitude recovery,
- Radar vector guidance towards terrain,
- Non-precision approaches,
- En-route alternate for non-IFR rated pilots encountering IMC, and
- Taxiing on complex taxi-routes.

The flight trial goal was to evaluate the objective performance of pilots for the different display configurations. As dependent variables, positional and time data were measured. Analysis was performed by an ANOVA test. In parallel, all pilots answered subjective NASA Task Load Index, Cooper-Harper, Situation Awareness Rating Technique (SART), and questionnaires.

The result shows that pilots flying 2D/3D SVS perform no worse than pilots with conventional systems. In addition, 3D SVS flying pilots have significantly better terrain awareness, more stable 180° deg turns, and enhanced positional awareness while taxiing on the ground. Finally, even non-IFR rated pilots are able to fly non-precision approaches under IMC with a 3D SVS.

Introduction

Within the framework of the NASA Aviation Safety Program for Synthetic Vision Systems (NCC-1-343), Jeppesen and its partners Marinvent and the Darmstadt University of Technology generated and evaluated terrain, obstacle, and airport databases [6].

A key component was the evaluation of 3D and 2D Synthetic Vision display formats [5]. The display format depicts navigation, terrain, and obstacle data for approach, landing, and taxiing. The 2D display is based on standard Jeppesen chart symbology and layout. This electronic chart is overlaid by a moving map symbol that shows aircraft position and track. A Jeppesen chart symbology compliant 3D format is also available [5]. It shows an egocentric view out of the cockpit window. Traditional chart color coding and symbology is adopted for this 3D display [5]. The 3D depiction is used solely for flight guidance.

Reno Flight Trials Overview

Test Area

The flight trial test site was located in western Nevada, centered at Reno/Tahoe airport, at N 39° 30’ W 119° 46’ and an elevation of 1350m MSL. Reno is located on the western edge of the Great Basin, in a semi-arid valley just at the east of the Sierra Nevada Range. The test area extends to an area of a 50 nautical miles radius from the Reno airport. The test area is characterized by rough terrain, undulating between 402m and 3306m.

Hardware Environment

The test-bed aircraft used to perform the flight trials was the Piper Cheyenne I Super 500 of Marinvent Cooperation (see Figure 1). It is designed specifically for human factors and systems flight test missions.

Technical features of that aircraft are:

- "Glass-cockpit" with dual two tube EFIS and state of the art avionics (the cockpit could be modified in a short duration – app. 2 h – to support 3D SVS)
- Distributed data architecture supporting ARINC 429.
- Digital air data and six axis AHRS feeds.
- Digital cockpit audio and video recording for post-flight playback and analysis.
- Time-synchronized GPS information and air data.

Figure 1. Marinvent Cheyenne I Super 500

2D Navigation Display

For the 2D Navigation display, the UPS Aviation Technology MX-20^{TM} was used as hardware [1] (see Figure 2). The MX-20 ^{TM} is a combined rendering and display unit, designed and tested to meet FAA TSO-C113 [2].

Figure 2. UPS-AT MX20^{TM}

3D Primary Flight Display Hardware

For the 3D PFD, a COTS Laptop (Dell Precision M-50) was used as rendering unit (see Figure 3).

For the flight trials and the evaluation period, a display device was integrated into the copilot's instrument panel with the rendering unit installed in the aft cabin. On the 3D PFD (see Figure 3 and Figure 5), a 3D depiction of the aircraft environment in a first person view from the pilot position was displayed.

As an in-cockpit display device, a derivative of a commercial Rockwell Collins 8" x 8" LCD cockpit display was provided (see Figure 3).

Figure 3. Laptop and Rockwell-Collins LCD

Electronic Flight Information System (EFIS)

For the standard display, a basic Meggitt^{TM} EFIS was used [3]. A system like this can be found in a wide range of airplanes (see Figure 4).

Figure 4. Meggitt^{TM} EFIS

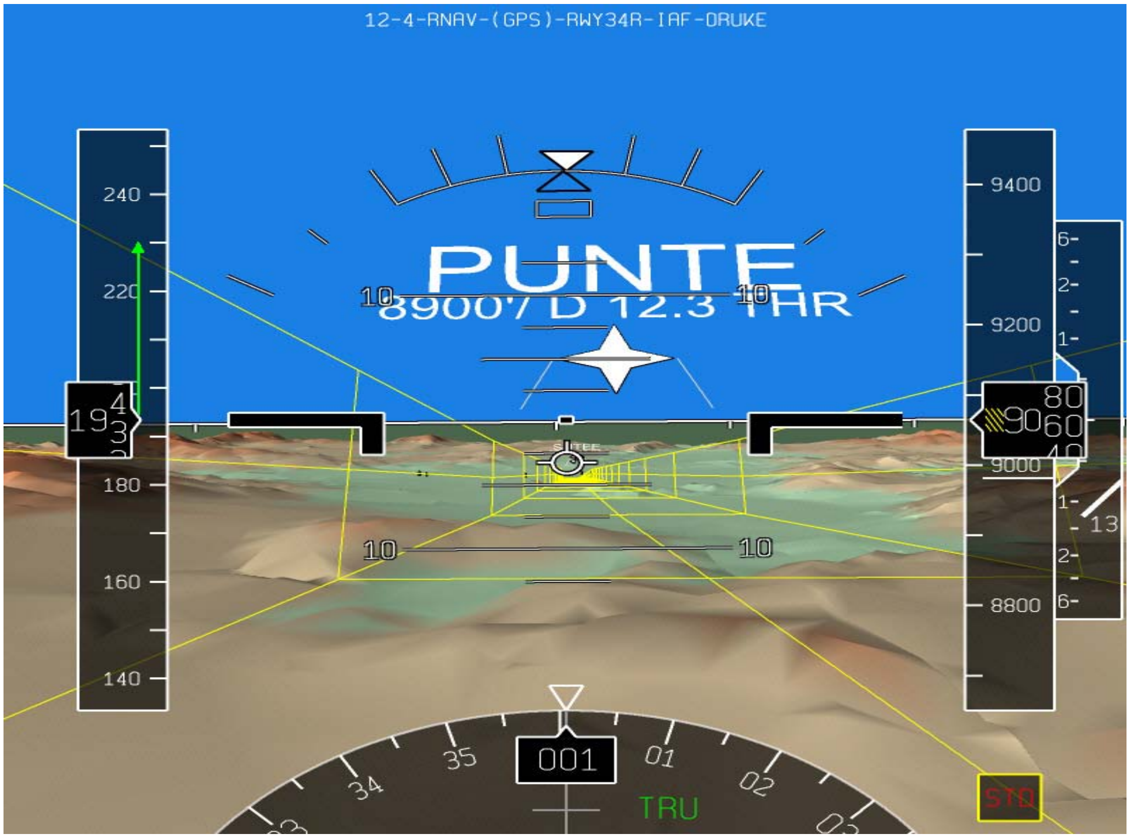


Figure 5. FliteDeck 3D (F3D) Display

2D Moving Map (ChartView™) with EFIS

The moving map charts in ChartView™ [4] are based on the Jeppesen Electronic Charts. Jeppesen instrument approach charts and airport-surface diagrams are viewed with the aircraft position overlaid on the MX20™ display (see Figure 6). The MX20 with ChartView™, a panel-mounted aircraft instrument integrates Jeppesen electronic instrument approach and airports surface charts in a moving map display. ChartView™ displays Standard Instrument Arrival and Departure charts (SIDs and STARs).

On departure, the MX20 with ChartView™ displays the airport surface map, including all runways and taxiways. After takeoff, the MX20 automatically transitions to the enroute chart which depicts airways, airspace, terrain, navaids, rivers, lakes and highways. Within the terminal area of the destination airport, the MX20 transitions to the selected instrument approach plate - complete with procedure turns and holding patterns. Once the aircraft has approached the runway and ground speed has slowed down to 50 knots, the aircraft symbol is displayed on a moving map of the airport surface.

Figure 6. UPS ChartLink™ depicting electronic moving map data from Jeppesen

FliteDeck3D (F3D)

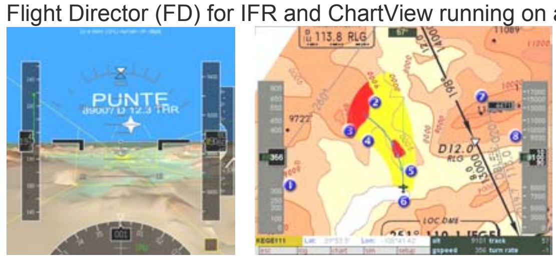
FliteDeck3D three-dimensionally depicts the following information [5]:

- terrain data,
- obstacle data,
- airport data,
- navigation data, and
- cultural data.

FliteDeck3D provides the capability to select flight procedures like SID's or approaches. The selected procedure is displayed three-dimensionally on the 3D PFD (see Figure 5). For the 3D depiction of the procedures, a tunnel-in-the-sky concept is used. The tunnel-in-the-sky has the following dimensions: 250m width, 100m height, and 600m segment spacing (see Figure 5).

Baseline EFIS with Flight Director (FD) for IFR or without FD for VFR and conventional paper charts

Baseline EFIS with Flight Director (FD) for IFR and ChartView running on an MX-20



F3D with Tunnel-in-the-Sky and SmartChart

Figure 7. Display Configurations

At a distance of 5 NM from the threshold an approach tunnel-in-the-sky starts to narrow from the dimensions above to 20% of these dimensions at the threshold. A SID tunnel-in-the-sky starts with 200% of the dimensions above to the dimensions above at 5 NM distance to the threshold.

During the flight trials no flight path indicator was displayed on the 3D PFD (see Figure 5).

Flight Trial Concept

The flight trial goal was the evaluation of the general aviation SVS concept of Operations.

Research Display Configurations

Three different display concepts were evaluated as independent variables (see Figure 7):

- Conventional flight instrument displays (EFIS) with paper navigation charts
- Conventional flight instrument displays (EFIS) with an additional electronic navigation charts (ChartView)
- 3D primary flight display (F3D) with terrain, obstacle, airport and flight procedures as background information and tapes as overlay and an enhanced 2D navigation display (SmartChart).

Conduction of Flight Trials

Thirteen pilots participated as test subjects in the flight trials. Seven pilots were IFR rated, five of them had a CPL license and two an ATPL license. Four of the IFR rated pilots were professionals with an average of 4775 flight hours. The average number of flight hours for all IFR rated pilots was 3407 hours. The average number of hours flown as pilot in command with IFR rating was 1425.

Six test subjects were VFR-only rated pilots from local flying clubs. Five of them had a PPL-A license, one a CPL license. Their average flight experience was 203 hours.

The total number of flight hours for all of the test subjects ranged from 47 hours up to 12000 hours with an average of 1928 hours. The age of the test subjects was between 22 years and 63 years with an average of 42 years.

Prior to every test flight, a briefing was conducted. Test subjects were introduced to the different SVS display concepts. After the introduction, the display and the maneuvers for the following test flight were described. The safety pilot gave an introduction to the safety procedures and the handling of the test aircraft. Most of the test subjects had no experience with a twin-engine turboprop aircraft.

The safety pilot performed the take-off and once leveled off, the test subject was given time to get familiarized with the aircraft and its controls. As the task for the flight trials was to evaluate different displays, test points were flown only with the help of the instruments and the current tested display. Therefore, the test subjects wore goggles while conducting the test scenario to prevent them from looking outside.

During the test flight the safety pilot was responsible for the proper positioning and configuration of the aircraft for every test point. At the beginning of every test point, the test subject was given control over the controls, flying the dedicated maneuver and returning the controls back to the safety pilot after completion of the task. After every scenario, the test subject was given a list of questions concerning the level of assistance from the current display and the workload during the maneuver. While the subject answered the questionnaires, the safety pilot positioned the aircraft to the beginning of the next test point, so the test flight could continue without interruption. During the whole test flight the safety pilot was responsible for aircraft configuration, navigation, thrust control and contact to ATC, so the test subject could fully concentrate on the given tasks.

A debriefing was conducted after every test flight to get a more detailed description of the pilots' impression from the display that was used. This way a lot of information about why a special display was helpful for a special task or why a task could not be finished, could be collected.

A strong learning effect concerning the handling of the Cheyenne, reading the instruments, flying an aircraft with SVS equipment or even getting used to the area around Reno, NV would have been an influencing factor on the results. Therefore, the structure of the flight test was completely randomized. Test subjects flew the different display concepts in different orders and on the different flights for each test subject. Test points have been randomized.

For all statistical analysis the statistical significance level was set to 5% ($\alpha \leq 0.05$). The Type I Errors, that the null hypothesis is rejected in favor of the experimental hypothesis when in fact the null hypothesis is true lies under $p \leq 0.05$.

Steep Turns & Reversals

This test scenario serves to evaluate the system, FliteDeck3D (F3D) symbology and to examine if this basic maneuver could be conducted within the performance tolerances in accordance to the maneuvers.

It is hypothesized, that test subjects using a 3D PFD (F3D) can achieve similar performance in maintaining desired bank (45°) and altitude compared to the same maneuver using an EFIS PFD.

Participants

This task was performed by the seven IFR rated pilots.

Apparatus

The achieved performance using the 3D display had to be compared to the performance achieved using the baseline EFIS (see Figure 8).

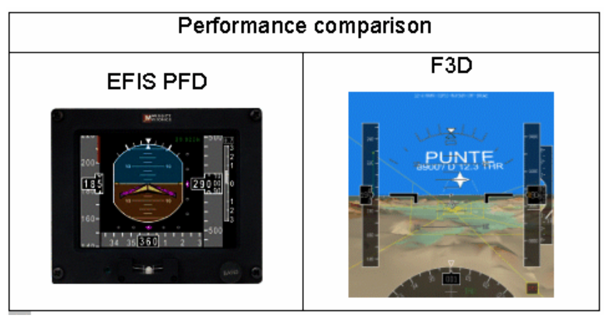


Figure 8. EFIS compared to F3D

Procedure

For evaluation of the SVS, test subjects had to perform a steep 360° turn with 45° bank followed by a reversal maneuver.

Upon task completion, pilots answered a Display Flyability Rating and a NASA TLX questionnaire.

Results

All seven pilots completed the maneuver within a five-degree deviation heading. Mean altitude deviation was smaller using the EFIS compared to F3D. Standard altitude deviation was higher. Flown altitude range within that task was higher using F3D (see Figure 9).

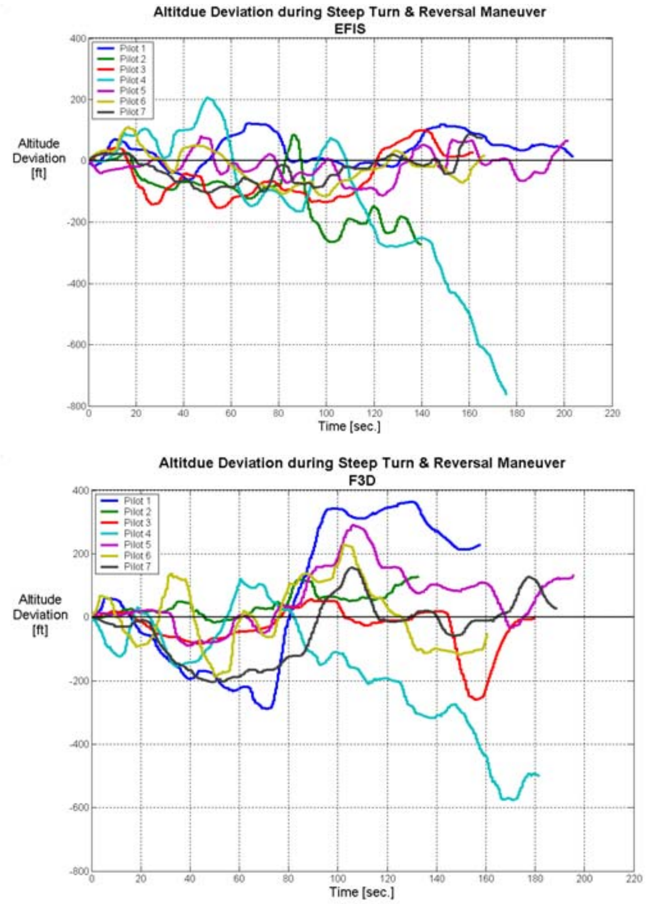


Figure 9. Altitude Deviation during Steep Turn & Reversal maneuver using EFIS (top) and F3D

A correlation analysis revealed a strong relationship between each individual pilot performance using the EFIS PFD and F3D. Pilots who performed well flying the steep turns also performed well using F3D (see Figure 9 and Figure 10).

A Wilcoxon test served to compare the distribution of both display variables. The null hypothesis indicates the same distribution in altitude for both displays used (level 0.15).

ANOVA analysis showed no differences in flown mean altitude deviations. Referring to the altitude deviation mean values no display type shows to be superior over the other.

A conducted ANOVA analysis showed no differences in the mean values of the desired bank of –45° and 45° for the reversal during the maneuver for both displays.

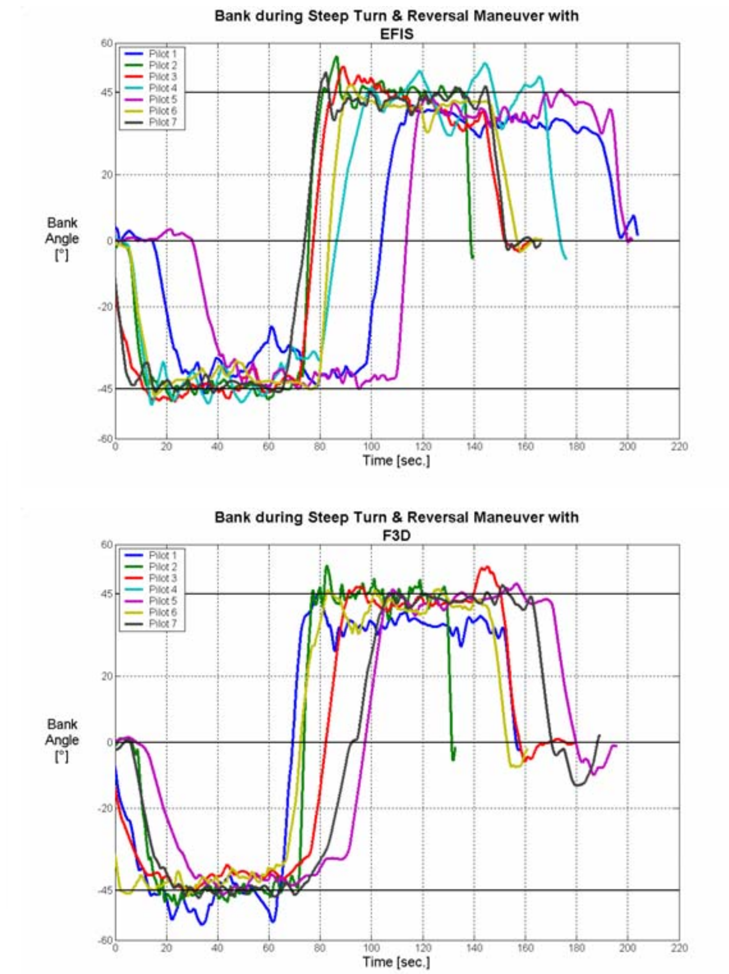


Figure 10. Bank Angle during Steep Turn & Reversal Maneuver with EFIS (top) and F3D

A Friedman-test, applied to determine significant differences between the two display types flown during this maneuver revealed no difference in distribution, but the null hypothesis was rejected for weighted defects in desired bank (-45° and 45°). The pilots flying F3D showed better performance in achieving the desired bank, as minor significant deviations in bank were recorded compared to maneuver flown with the EFIS (see Figure 10).

Although pilots performed better in terms of achieving the desired bank using F3D, they rated the display flyability of the 3D PFD (4.5) lower than that of the EFIS PFD (2.7). The NASA TLX revealed almost the same load index for F3D (27) and EFIS (26).

Discussion

The results of the steep turns and reversal support the initially stated hypothesis. Pilots flying F3D even showed better performance in achieving the desired bank.

Unusual Attitude Recovery

Two tasks were pursued with this task:

- The ability of F3D to support the pilot to recognize and recover compared to conventional attitude indication display (EFIS).
- Verify the appropriateness of the attitude information of F3D.

It is hypothesized, that test subjects (both IFR and non-IFR rated pilots) can recover from an unusual attitude within 1 sec reaction time and with no initial control reversals using a 3D PFD (F3D) compared to the times and reactions using an EFIS PFD.

Participants

This task was conducted with seven IFR and six non-IFR rated pilots.

Apparatus

This task served to evaluate how well the 3D PFD could assist the pilots in conducting this task compared to the PFD of the baseline EFIS (see Figure 11).

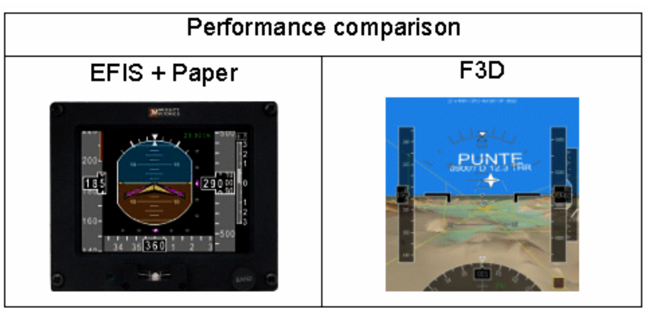


Figure 11. EFIS compared to F3D

Procedure

This task was arranged by the safety pilot, who slowly brought the aircraft into a 30° nose up or down together with a 45° bank left or right, while the test subject had his eyes closed. Upon the safety pilot's callout "you have control" the test subject opened his eyes to identify and react to the unusual attitude.

After unusual attitude recovery test subjects answered a Display Readability Rating and NASA TLX questionnaire.

Results

All seven IFR rated pilots responded to the unusual attitude within the desired time of one second flying both display types. No initial control reversals were performed during each recovery. Subjective results indicate an overall lower workload recovering with F3D (11.9) than with the EFIS PFD (16.6). Also F3D display readability was rated better than the EFIS.

Of the non-IFR rated pilots one pilot (16%) flying the EFIS did not react for three seconds after which the safety pilot had to take over. The remaining five pilots reacted within the desired one second after the safety pilot gave the controls to the test subject. All seven pilots recovering from the unusual attitude responded within the desired time and no initial control reversals were conducted. Pilot statements indicate the same perceived workload flying both display types. F3D received better display readability ratings than the EFIS for the recovery maneuver.

Discussion

The results of the unusual attitude recovery support the initially stated hypothesis. The 3D depiction of the outside world obviously assists non-IFR rated pilots in attitude recognition.

Radar Vector Guidance Leading Towards Terrain

During this task the test subject received simulated ATC bad radar vector leading towards high rising terrain (see Figure 12 and Figure 13).

It is hypothesized that through the use of a 3D PFD with terrain and obstacle depiction (F3D) in combination with a 2D moving map with terrain conflict preview (SmartChart) overall situational awareness will be increased and a developing obstacle or terrain conflict will be recognized earlier by the evaluation pilots compared to the use of a conventional EFIS with paper charts.

Participants

This task was performed by IFR rated pilots only.

Apparatus

This task was intended to determine the possible improvement in situational awareness achieved through using F3D in conjunction with SmartChart compared to a conventional EFIS with paper charts.

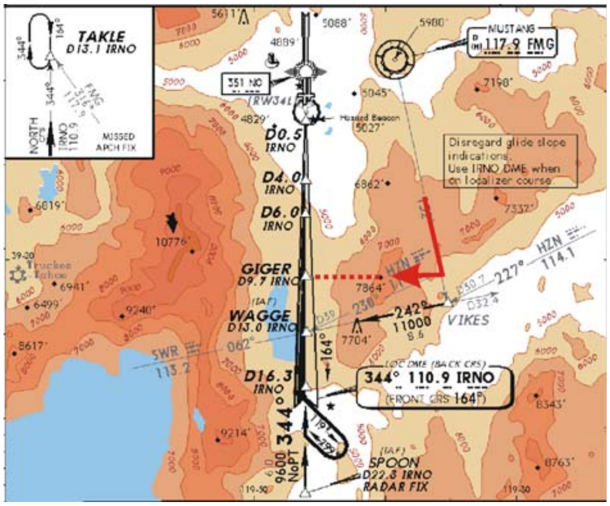


Figure 12. Simulated radar vectors leading towards terrain

Procedure

While the test subject wore goggles the safety pilot gave him radar vectors simulating ATC. These radar vectors led dangerously low towards high rising terrain (see Figure 12 and Figure 13).

Subjective results were captured through NASA TLX and SART in conjunction with a Stress and Level of Terrain Awareness Rating questionnaires.

Results

All IFR rated pilots flying the EFIS with paper charts did not notice the potential terrain hazard. All scenarios lead to a terrain clearance of approximately 800ft. One pilot noticed the radio altimeter being displayed on the EFIS PFD, but did not alarm the safety pilot until the EGPWS went off and the safety pilot took control.

50% of the pilots who flew the scenario with F3D and SmartChart detected the terrain threat, as the terrain color on SmartChart turned yellow. All pilots stated they saw the terrain in F3D, but could not estimate how high the terrain was rising relative to the current altitude flown.

The analysis of the questionnaires revealed a higher level of terrain awareness using F3D (6.7) compared with EFIS (3.8).

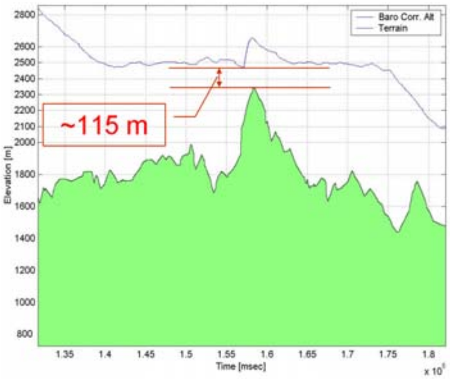


Figure 13. Profile View of a Typical Radar Vectoring Scenario towards Terrain

Discussion

The results fulfilled the hypothesis that pilots with a 3D display have better situational awareness. Still, the result that "only" 50% reacted on the terrain needs further evaluation. The subjective questionnaire indicated that the terrain looks too low. A future version of F3D shall address this.

Non-Precision Approaches

This Mission Task Evaluation (MTE) served to evaluate the pilot's navigational accuracy, workload and situational awareness using the

- baseline EFIS with no Flight Director (FD) in conjunction with ChartView and,
- F3D in conjunction with SmartChart

compared to the conventional EFIS without FD while conducting non-precision approaches. This task also served to evaluate display symbology of F3D. Only the lateral and vertical deviations at each fix during the approaches were regarded as they can only be considered in order to compare the flown navigational accuracy between each display configuration.

RNAV (GPS) and Localizer approaches were performed using three different display configurations.

It is hypothesized that through the use of an EFIS in conjunction with a 2D moving map display (ChartView) or through the use of a 3D PFD with displayed approach guidance (Tunnel-in-the-sky) (F3D) in conjunction with SmartChart, workload, situational awareness and flight path error at each fix during the approach will be decreased while conducting non-precision approaches (RNAV & Localizer approaches) compared to the same non-precision approach using an EFIS in conjunction with paper charts.

Participants

These non-precision approaches had to be conducted by IFR-rated pilots only.

Apparatus

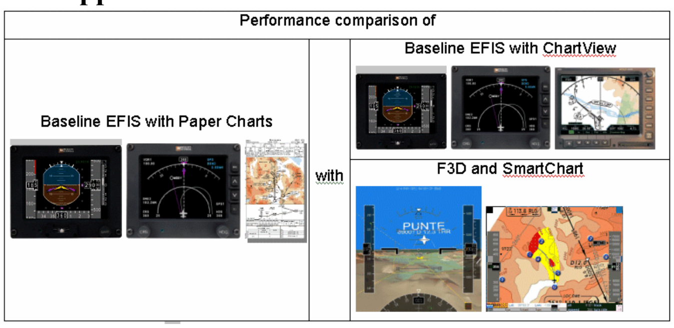


Figure 14. Displays configurations used for non-precision approaches

Procedure

The safety pilot flew the aircraft to the initial approach fix. The test subject wearing goggles took over the control of the aircraft and flew the approach using the instrument displays.

After each type of approach the pilots answered NASA TLX and SART together with a Stress and Level of Terrain Awareness Rating questionnaire.

Results

To compare the mean deviations at each waypoint between all three display configurations two statistical tests were applied. First an ANOVA was conducted to compare the mean deviations at each waypoint. Secondly, a Friedman-Test was performed to acquire further information about the differences between the mean deviations.

Results of RNAV (GPS) Approaches

Waypoint ROXJO: Lateral deviation at waypoint ROXJO is minor. The ANOVA procedure confirms the null hypothesis, as does the Friedman-Test. But vertical mean deviation of all three display configurations differ at this point so that the null hypothesis is rejected (ANOVA significance level 5%). The Friedman-Test revealed that F3D with SmartChart performed best, followed by the EFIS with paper charts and EFIS with ChartView.

Waypoint BADPE: At this waypoint no statistical difference in mean lateral or vertical deviation could be observed by the ANOVA and the Friedman-Test. All three display configurations showed similar performance.

Waypoint VDP: Also at the visual descent point no statistical difference between the display configurations were detected.

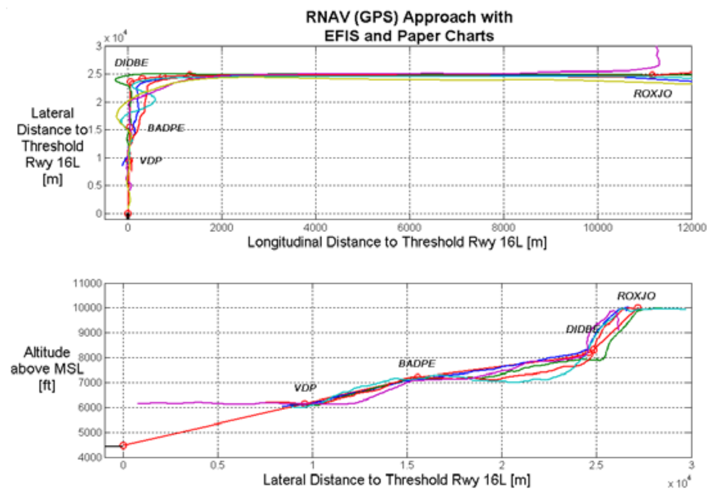


Figure 15. Data plots of RNAV (GPS) approaches using EFIS and paper charts

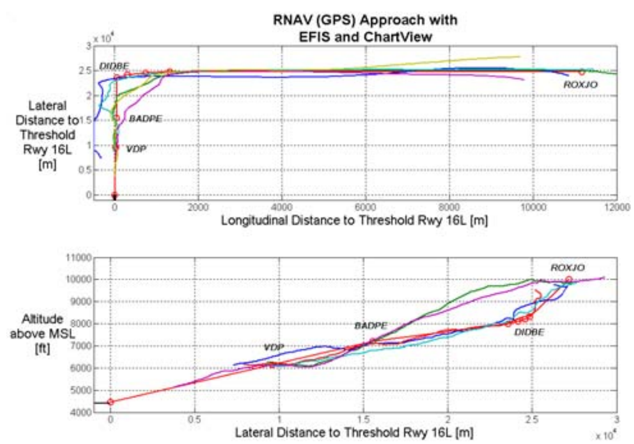


Figure 16. Data plots of RNAV (GPS) approaches using EFIS and ChartView

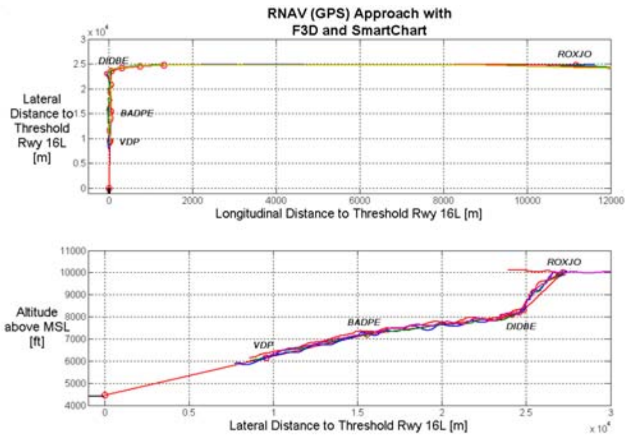


Figure 17. Data plots of RNAV (GPS) approaches using F3D and SmartChart

The Figure 15 to Figure 17 show a more accurate navigation performance after the curved segment using F3D in combination with SmartChart.

Results of Localizer Approaches

An examination of the conducted localizer approaches to runway 16R revealed similar results to the performed RNAV approaches.

Waypoint TAKLE: At TAKLE the comparison of the means does not show any conspicuousness. The significance levels lie between 11.4% and 87%. The Friedman-Test only narrowly manages to confirm the null hypothesis. The null hypothesis is confirmed at a level of 7.4% while the significance level lies at 5%.

Waypoint DICEY: At this waypoint, the statistical mean deviation of the different configuration types is nearly equal. The ANOVA confirms the null hypothesis that the display configurations perform equal.

Discussion

The outcome of the statistical analysis does not reveal that the pilots performed better with any display configuration. The significance levels are high, though it could not be significantly stated that the differences in the mean deviation are random or due to the different display configurations.

Enroute Alternate for Non-IFR Rated Pilots Encountering IMC

Today low time non-instrument rated pilots rely on easy to see visual cues such as highways and power lines to determine their present position while enroute. A pilot unintentionally flying into instrumental meteorological weather conditions, losing all outside visual reference, will at best keep the aircraft at a stable attitude.

The question arises whether a non-IFR rated pilot could follow a tunnel-in-the-sky in a stable flight condition, assuming this tunnel-in-the-sky could be displayed by any manner and would lead the pilot to an alternate airport safely avoiding terrain and obstacles where visual meteorological conditions exist.

It is hypothesized that a non-instrument rated pilot who encounters instrumental meteorological conditions can safely transition to an alternate airport where visual meteorological conditions exist through a tunnel-in-the-sky. The task is rated successful, if the test subject manages to stay within the tunnel and follow the tunnel-in-the-sky with all flight mechanical parameters within normal range.

Participants

This task was performed only by the non-IFR rated pilots.

Apparatus

For this purpose the pilots had to perform RNAV approaches from the initial approach fix using F3D in conjunction with SmartChart (see Figure 18).

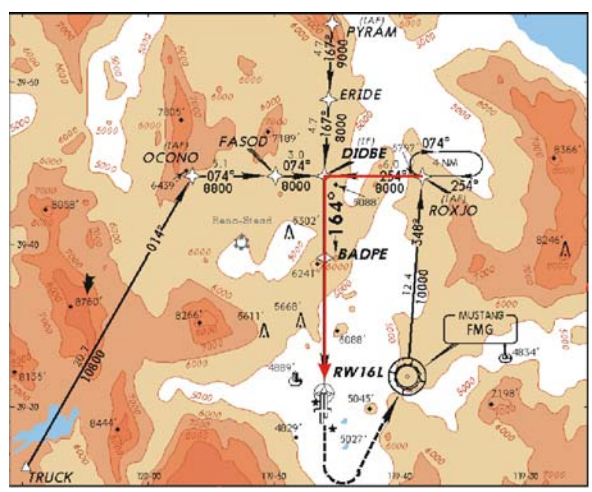


Figure 18. RNAV approach for non-IFR rated pilots

Procedure

The safety pilot flew the aircraft to the initial approach fix. The test subject wearing goggles took over the control of the aircraft and flew the approach using the instrument displays.

NASA TLX and SART in conjunction with a Stress and Level of Terrain Awareness Rating questionnaires were answered after the approach was flown by the test subject.

Results

All six non-IFR rated pilots flew the RNAV approach from waypoint ROXJO to the visual descent point without losing control of the aircraft. One pilot flew out of the tunnel during the 90 degree left turn to the runway but managed to reenter after the turn. Analyzed data revealed that the pilots deviated laterally out of the 250 m wide tunnel 13% mean time. No pilot deviated out of the tunnel vertically, which is 100m in height.

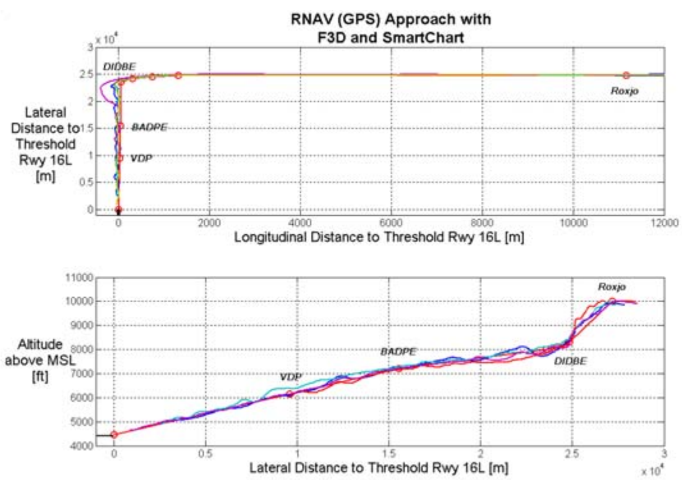


Figure 19. Data plots of non-IFR pilots conducting RNAV approach using F3D

High roll rates were observed for the majority of the pilots as they tried to keep the aircraft in the tunnel. Also a certain lack of awareness to reality could be observed as some maneuvers were flown aggressively during this scenario. This corroborates pilot statements as workload was rated high.

Discussion

The results support the initially stated hypothesis. The F3D depiction of the outside world and the tunnel-in-the-sky can obviously provide visual metrological conditions on a display.

Taxiing on complex taxi-routes

This task served to evaluate the pilot's positional awareness while following complex ATC taxi instructions. It is hypothesized that through the use of an aircraft spotter on a geo-referenced airport chart overall taxi errors will be minimized and taxi speeds will increase, producing less required taxi movement times.

Participants

This task was conducted by both IFR and non-IFR rated pilots.

Apparatus

This task served to determine the improved positional awareness of pilots taxiing on complex taxi-routes using ChartView™ or the research Jeppesen Taxi Positional Awareness function (TPA) (see Figure 20).

The ChartView™ airport layout chart features an aircraft spotter overlaid on the traditional geo-referenced Jeppesen airport chart, providing actual positional information on the airport. TPA additionally provides information concerning parking stands, runway safety area, useable taxiway surfaces and taxi lines. Also all taxiway identifications are located on the corresponding taxiway and between taxiway intersections. Both ChartView™ and Jeppesen TPA ran on the MX-20™. IFR-rated pilots conducted the complex taxi scenarios using all three airport charts, while the non-IFR rated pilots used the traditional Jeppesen chart and the TPA only.

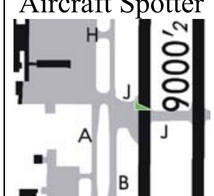
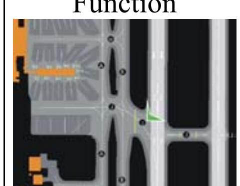
Jeppesen Airport Layout Paper Chart	ChartView Airport Layout Chart with Aircraft Spotter	Research Taxi Positional Awareness Function
		

Figure 20. Taxi Speed and Positional Awareness Comparison

Procedure

ATC was informed to assign a complex taxi procedure from the parking ramp to the departure runway and back for this task (see Figure 21). The safety pilot was responsible for all ATC communications. The test sortie was instructed to execute the taxi instructions using the throttles. Each complex taxi scenario consisted of at least one Hold short instruction and two turns at intersections. The following figure shows an example of complex taxi route scenario. After the scenario each test subject was handed a Situational Awareness Rating Technique (SART) and a Display Readability Rating (DRR) questionnaire.

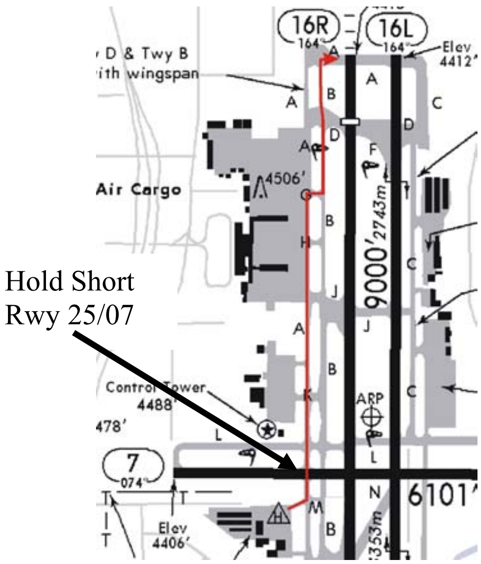


Figure 21. Complex taxi route

Results

A total of 61 complex taxi route movements were conducted. These consisted 43 performed by IFR-rated pilots and 18 non-IFR rated pilots.

A conducted one-way ANOVA revealed no significant difference in taxi speeds among the three different charts (0.79).

Subjective results reveal that average perceived Situational Awareness (SA) among all three airport charts is highest using TPA (14.37), followed by the traditional Jeppesen airport chart (12,85) and ChartView™ (12.7). This is also reflected by the statements made through the display readability ratings, whereas information is best readable through the use of the TPA (1.81), followed by the standard Jeppesen airport chart (2,07) and ChartView (3.66)

Pilot taxi errors occurred once for both airport charts. A McNemar-Test indicated no significance.

The average SA perceived by the non-IFR rated pilots shows similar results to the values given by IFR-pilots. Again Jeppesen TPA showed increased average SA (10,43) over the traditional Jeppesen airport chart (9.5). DRR stated better information depiction for Jeppesen TPA (1.765) than the Jeppesen airport chart (2.1).

Discussion

The hypothesis that the average taxi speeds would increase using a plane spotter on a geo-referenced chart was rejected. Also the hypothesis that pilot taxi errors would significantly diminish was also rejected although they occurred. For Jeppesen TPA, the workload is lower as it was hypothesized.

Conclusions

These flight trial results are very encouraging for the commercial introduction of 3D SVS. They demonstrate that 3D SVS guarantee equal and/or better situation awareness (see Table 1). In addition, navigation performance is improved under certain situations (see Table 1). Even under involuntarily encountered IMC situations it could greatly benefit VFR pilots to recover.

Setting / Scenario	EFIS & Paper Charts	EFIS & ChartView	F3D & SmartChart
Steep Turns & Reversals	insignificant	-	insignificant
Unusual Attitude Recovery	insignificant	-	insignificant
Radar Vectors towards Terrain	insignificant	-	insignificant
RNAV (GPS) approaches	insignificant	significant	significant
Localizer approaches	insignificant	significant	insignificant
Taxiing on complex taxi-routes	insignificant	insignificant	insignificant

Table 1 Flight Trial Summary

Mid 2004, a second set of flight trials will be conducted to validate further system improvements.

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References

[1] UPS Aviation Technologies, 2000: APOLLO Model MX20 Multi Function Display, User's Guide, Software Version 2.3

[2] FAA TSO-C113, 1986: Airborne Multipurpose Electronic Displays, FAA, Washington D.C.

[3] Meggitt Avionics, 2001: MAGIC, Electronic Flight Instrument System, Meggitt Avionics

[4] UPS Aviation Technologies, 2000: APOLLO MX20 Multi Function Display, Installation Manual, part # 560-1025

[5] J. Schiefele, P. Wipplinger, T. Wieseman, W. Kubbat, B. Hibbard, D. Howland, Flitedeck3D on the MX20, SPIE, Vol. 4713, Orlando, FL, April, 2002

[6] J. Schiefele, W. Kearse, C. Parrish, A. Friedrich, W. Kubbat, "RTCA/EUROCAE: Airport and Terrain Database Acquisition for Aviation Applications", Flight Safety Foundation, IASS 2001, Athens, Greece, November 2001